PROTEIN QUALITY AND QUANTITY IN CEREALS. NUTRITIONAL VERSUS GENETICAL FACTORS

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INTRODUCTION

It is a well known fact that, although an increasing agricultural production has succesfully met the equally increasing caloric demand of mankind, the closing of the so called protein gap is becoming more difficult to solve every day.

Plant breeders and plant nutritionists alike have become aware of the urgent need to include protein quantity and quality alongside crop yield as their high priority objectives.

Cereal grains have been and will continue to be for some time the main protein source for most of the world. Genetic and nutritional methods to increase and improve cereal protein are therefore of great importance in modern agriculture.

The purpose of this paper is to discuss current ideas about the interplay of genetic and nutritional factors affecting cereal protein yield and quality. Although we will not restrict the discussion to our data and will include abundant data from many workers, a systematic review of the subject is beyond the scope of this contribution. Furthermore, mostly data from wheat will be used to support the discussion.

Genetic versus environmental control of kernel protein

Both protein quantity and quality are under strong environmental influence. This is illustrated in figure 1, where the variation of protein content and sedimentation value of two wheats, sampled in 1968 at 40 sites each, is represented against the background of the distribution of mean values of 32 wheats grown in Spain during the same year (1). Indeed,

JOHNSON and others (2) have examined protein content of 16,000 wheats from the World Collection and concluded that most of the protein variation among them is non-genetic in nature.

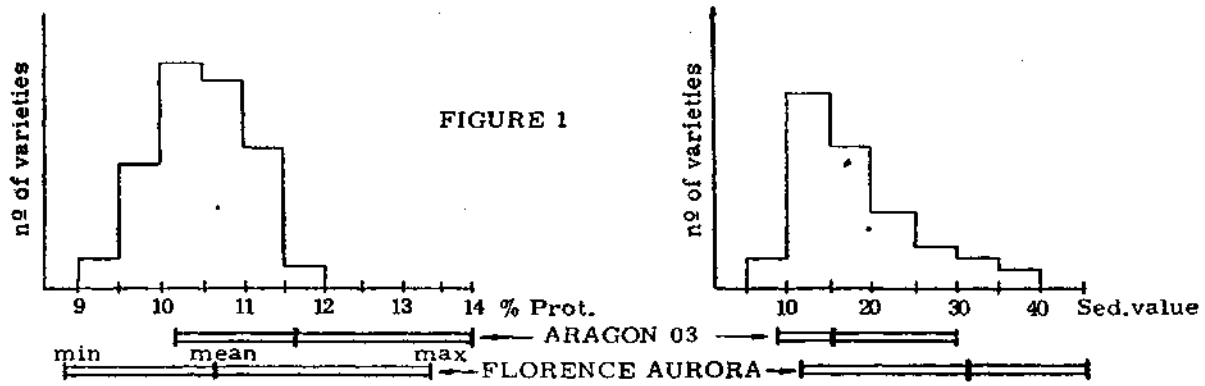

FIGURE 1

However, the two wheats in figure 1 differ both in their mean values and in the intervals of variation. These differencies must be genetically controlled. BUSH and others (3) have treated genotype x environment interactions for quality characters by a quantitative method similar to that proposed by FINLAY and WILKINSON (4). Eight varieties were grown in 57 environments. The mean value of each characteristic for all entries in a nursery was used as the index of that environment for that characteristic. The mean of all environments was used as a constant, and the environments were coded by the difference of their respective means with the overall mean. Values for each variety were regressed linearly against the environment value. Their results for protein content are presented in figure 2. We can see that the varieties tested differ both in their performance (Justin above Thatcher and Polk in all environments) and their stabilty (Polk more stable than Justin, Justin more stable than Thatcher).

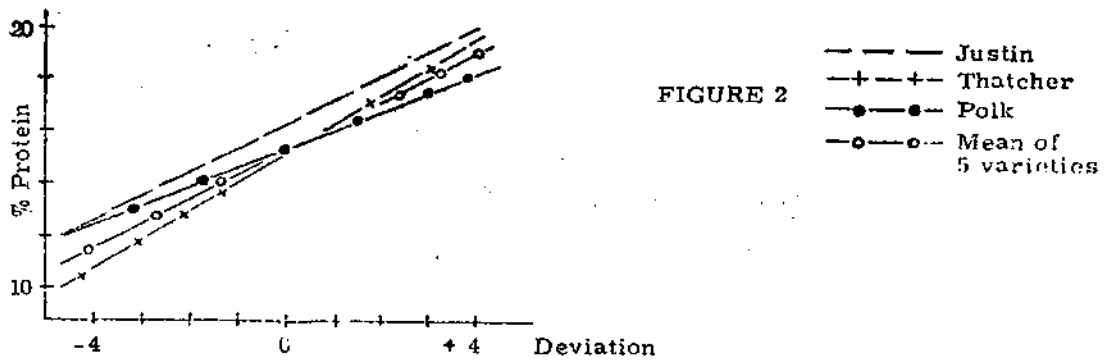

FIGURE 2

So far we have considered the environment as a whole, without specifying any particular environmental factor, and analyzed its impact on protein. Now we will focus on nutritional factors, which are the more easily

manipulated components of the environment. We will consider as nutritional factors both mineral nutrients and metabolic modifiers.

Effect of nutrients on kernel protein

Fertilizers and water supply control to a great extent cereal kernel protein. This problem has been extensively investigated in the case of wheat by several workers (5-16 & others) and a general picture can be drawn from their results.

Nitrogen has a direct effect on kernel protein, while water supply and other nutrients have a more indirect effect.

If nitrogen is limiting for kernel development, increases in the nitrogen supply will result in grain and protein yield increases. Stimulation of kernel development by small increases of nitrogen can be greater than the stimulation of kernel protein synthesis and result in lower protein per cent. This has been clearly shown by SCHLESINGER (8). At higher nitrogen doses, however, protein synthesis can be increased in a greater proportion than kernel development and a greater yield of grain with a higher protein per cent can be achieved.

Time of nitrogen application is critical for maximum kernel protein content. It has been repeatedly shown that spring application consistently gives higher protein contents than fall application (7, 15, 16). Pertinent data from HUNTER and STANFORD (15) is plotted in figure 3. Furthermore, JAHN-DEESBACH and others (16) have demonstrated not only the effectiveness of late nitrogen in increasing protein content but also its favorable effect on the proportion of vitreous kernels.

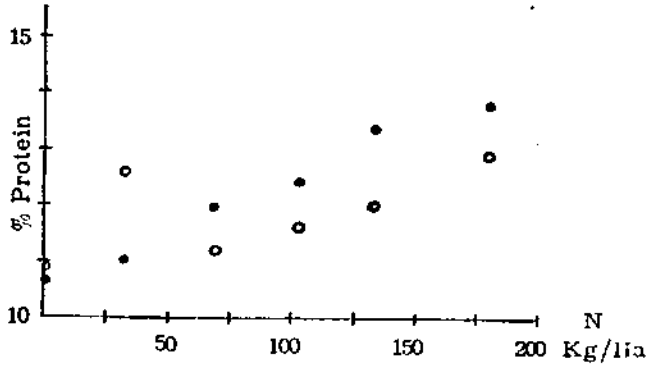

FIGURE 3

Under conditions in which nitrogen is not limiting for kernel development, yield increases in response to other nutrients or to water supply will have a dilution effect on protein. In other words, protein percent decreases even if some increase in protein yield per hectare is observed. That irrigation brings down protein per cent has been extensively documented

(5, 9 & others). This is also the basis for the negative correlation between yield and protein content which is often, but not always, observed (2). SCHLESINGER (8) has demonstrated, however, that protein per cent can be increased at the same time as protein yield if nitrogen supply is concurrently increased.

Considerably less information is available about effect of nitrogen source and form of application on kernel protein. ALESSI and POWER (13) have compared nitrogen sources for small grain production in semiarid regions and have found that nitrate and ammonium were clearly superior to urea formaldehyde. ALKIER and others (11) in Manitoba, have concluded that although both soil and foliar postemergence nitrogen application can increase protein content, a greater proportion of soil applied nitrogen (ammonium nitrate, urea, or ammonium sulfate) was absorbed into the grain than when applied to the foliar surface.

Effect of metabolic modifiers

In a broad sense, metabolic modifiers can be considered nutritional factors. The exciting possibility of selectively changing genotype-phenotype correlations with the aid of physiologically active substances has been realized during the last decade. A brief mention of CCC (2-chloroethyl trimethyl ammonium cloride) and of s-triazines effects is therefore warranted.

The effect of fertilizer nitrogen, irrigation and CCC in wheat has been recently investigated by GASSER and THORBURN (17). CCC spray increased percentage of dry matter of the irrigated crop and decreased it in the unirrigated crop with all amounts of fertilizer nitrogen. CCC also increased the percentage of nitrogen in the straw and decreased it in the ear.

RIES and others (18) discovered that sub-lethal levels of the herbicide simazine could increase protein content in plants grown on sub-optimal nitrate supply. They further established that probable cause of protein increase was a marked enhancement of nitrate reductase activity in response to simazine treatment.

Active investigation by many groups is under way to fully explore the practical application of these and other metabolic modifiers (19-21).

Protein quantity versus quality

Nutritive quality of cereal protein is low. The limiting essential amino-acid in this protein is lysine.

JOHNSON and others (2) have found a negative correlation between protein content and lysine in the wheat World Collection. Protein differences at the lower levels exert a marked effect on lysine, but at higher levels,

above 16 % protein, this effect disappears. This negative correlation holds in general for all cereals. However, in some cases it can be broken genetically thanks to major genes that can alter drastically protein composition. Well known are the cases of maize, barley and sorghum.

In fact, the altered aminoacid composition of total protein seems to be the result of the preferential enhancement of certain proteins with a defined aminoacid profile and not vice versa.

Many investigators have found that nutritional increase of kernel protein affects mainly certain protein solubility classes (5, 7, 10). Typical results are those of ABROL and others (10): kernel protein increase is localized in the endosperm and affects mainly prolamins and to a lesser extent glutelins; albumins and globulins being practically unchanged. Prolamins have a very low lysine content and thus a lower level of lysine appears in total protein. The opaque-2 gene that controls high lysine in maize acts by blocking prolamin synthesis, thus enhancing the other protein classes which are richer in lysine.

There is little information concerning how nutrient balance affects protein solubility classes and the components of this classes. HOJJATI and MALEKI (12) have studied the effect of nitrogen and potassium fertilization on lysine, methionine and total protein content of wheat grain and found that potassium could significantly increase lysine without decrease in protein yield when applied at certain levels. Undoubtedly, moore information is needed about response of protein components or groups of components to fertilization before that technical and economical feasibility of nutritional manipulation of protein quality can be ascertained.

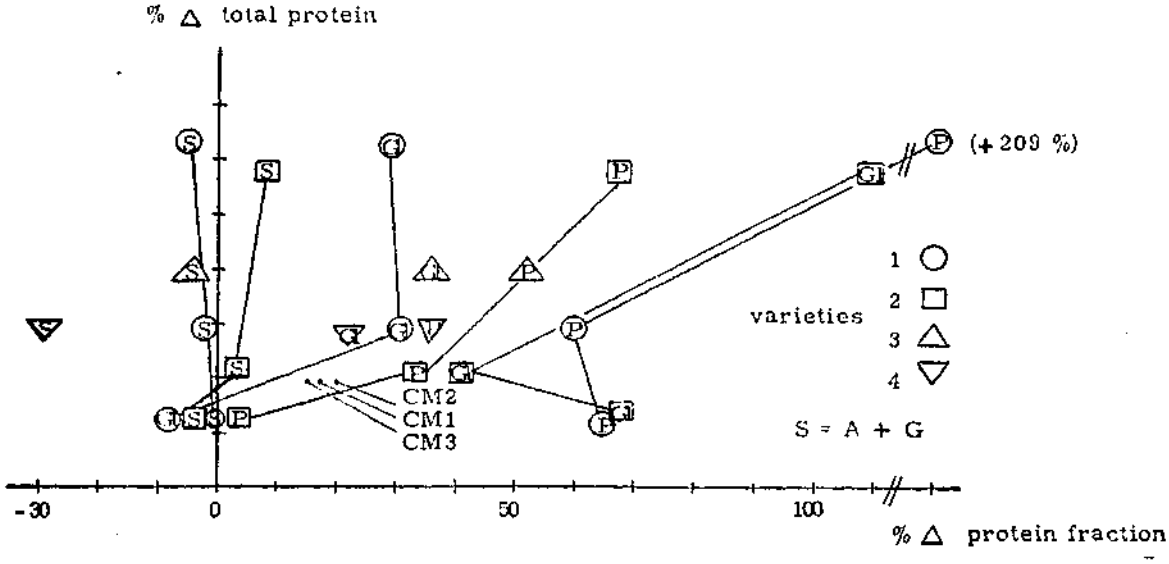

FIGURE 4

We have developed a method to measure the variation of individual protein components in genetic and fertilization experiments that can be applied to very small samples, even to half-kernels. Protein solubility classes are obtained at a preparative scale, dialized and liophylized. Appropriate dilutions of the liophylized protein are subjected to starch gel electrophoresis together with replicates of the direct extracts from the experimental samples in a gel slab, where up to 30 samples can be handled. After staining, each individual component is measured densitometrically and expressed in arbitrary units by interpolation in the standard curves obtained for each component from the electrophoretic profiles of the dilution series. The response of individual components of gliadins (CM1, CM2 and CM3) is plotted against total protein response in figure 4. Albumins (A), Globulins (G), prolamins (P) and glutelins (Gl) are similarly plotted. These data seem to indicate that there is ample room for nutritional manipulation.

SUMMARY

Cereal grains will continue to be for some time the main protein source for most of the world. Both protein quality and quantity are under strong environmental influence. Although genotypes differ in their potential for protein production and in the stability of protein to environment factors, fertilizers and water supply control to a great extent cereal kernel protein. Metabolic modifiers can alter genotype-phenotype relationship and can be of practical use in connection with protein composition.

A method is proposed to measure response of individual protein components in genetic and nutritional experiments.

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